SPECIFICATION

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OPTICAL VIA FOR THREE DIMENSIONAL INTERCONNECTION

Background of Invention

[0001] This invention relates to a system and method for the efficient coupling of radiation between optical devices and more particularly from a radiation source to a waveguide.

[0002] When coupling the output of a laser, such as a vertical cavity surface emitting (VCSEL), or a multimode optical fiber into a thin waveguide (e.g., a planar waveguide or an optical fiber), there may be large and unacceptable mode and size mismatches between the laser output mode and the modes that can be supported by the thin waveguide. These mismatches lead to correspondingly large radiation losses between the optical components. Until now these significant losses have been ignored or overcome by simply increasing the output power of the VCSEL so that a desired amount of energy is coupled into the waveguide.

[0003] In the new generation of opto-electronic components one key factor is the size thereof. On the one hand power must be limited to the minimum possible, while on the other, high power is desirable to guarantee good performances such as speed (or bandwidth) and signal/noise ratio. Thus, any power loss is at the expense of device performance. In addition, thermal and cooling issues arise at higher powers. Also, the lifetime of the VCSEL may be impaired if it is overdriven. Yet further, nonlinear or abnormal behavior such as undesired noise, distortion of output signals, etc. may result when a VCSEL has been overdriven.

[0004]

Thus, there accordingly remains a need in the art for a system and method for the

efficient coupling of radiation from a radiation source to a waveguide, or other optical component, without suffering excessive radiation losses at optical interconnections.

Summary of Invention

[0005] An optical coupling system for coupling optical energy between optical devices comprises a waveguide receptive of N-mode radiation from a radiation source where N is an integer. The waveguide comprises a first section receptive of the N-mode radiation from the radiation source and has a thickness of "h". A second section has a thickness of "t" wherein "t" is less than "h". A tapered section has a first end thereof with a corresponding thickness of "h" joined with the first waveguide section and a second end thereof with a corresponding thickness of "t" joined with the second waveguide section for coupling the N-mode radiation from the first waveguide section to the second waveguide section. Furthermore, the first section has a width of "q" and the second section a width of "w" less than "q." The first end of the tapered section has a corresponding width of "q" joined with the first waveguide section and the second end of the tapered section has a corresponding width "w" joined with the second waveguide section.

[0006] [0006] In a second embodiment, a cladding has a thickness of "c" and a refractive index of n_w, and is receptive of the N-mode radiation. The second waveguide section has a segment thereof positioned within the cladding and has a thickness of "t", wherein "t" is less than "c" and a refractive index of n_c wherein n_c is greater than n_w.

[0007] [0007] In a third embodiment, a waveguide has a refractive index of n_w and is receptive of the N-mode radiation along an axis. The waveguide comprises a first section receptive of the N-mode radiation and a tapered section receptive of the N-mode radiation from the first waveguide section. A third section is positioned within the tapered section and has a refractive index of n_c and receptive of the N-mode radiation from the tapered section; wherein n_c is greater than n_w.

[0008]

The tapered section comprises a first aperture having a first cross sectional area receptive of optical radiation and a second aperture having a second cross sectional area less than the first cross sectional area and receptive of the optical radiation from

the first aperture.

Brief Description of Drawings

[0009] Figure 1 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source by way of a prism wherein the waveguide includes a first section, a second section and a tapered section;

[0010] Figure 2 shows an arrangement of a waveguide encased in a cladding and receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section and a tapered section;

[0011] Figure 3 is a graphical representation of the normalized power coupled into the waveguide of Figure 2 as a function of distance therealong;

[0012] Figure 4 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section and a tapered section and the second section has a refractive index different than that of the first section;

[0013] Figure 5 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section, a third section and a tapered section, and the second section has a refractive index different than that of the first section;

[0014] Figure 6 is a graphical representation of the normalized power coupled into the waveguide of Figure 8 as a function of distance therealong;

[0015] Figure 7 is a graphical representation of the normalized power coupled into the waveguide of Figure 5 as a function of distance therealong;

[0016] Figure 8 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section and a tapered section, the second section has a refractive index different than that of the first section and a segment of the second section is positioned within the tapered section;

[0017] Figure 9 shows an arrangement of a waveguide receptive of N-mode radiation

from a radiation source wherein the waveguide includes a first section, a second section and a tapered section, the second section has a refractive index different than that of the first section and a wedge-like segment of the second section is positioned within the tapered section;

[0018] Figure 10 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section and a tapered section, the second section has a refractive index different than that of the first section and a wedge-like segment of the second section is positioned within the tapered section;

[0019] Figure 11 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section, a second section and a tapered section, the second section has a refractive index different than that of the first section and the second section encompasses the tapered section and the first section;

[0020] Figure 12 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section wherein the second section includes a segment thereof positioned within the first section;

[0021] Figure 13 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof positioned within the first section, the second section includes a symmetric wedge-like segment;

[0022] Figure 14 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof positioned within the first section, the second section includes an asymmetric wedge-like segment;

[0023] Figure 15 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second

section having a refractive index different than that of the first section and wherein the second section includes a segment thereof positioned within the first section and the first section is partially truncated;

[0024] Figure 16 is a graphical representation of the normalized power coupled into the waveguide of Figure 15 as a function of distance therealong;

[0025] Figure 17 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including a symmetric wedge-like segment positioned within the first section and the first section is partially truncated;

[0026] Figure 18 is a graphical representation of the normalized power coupled into the waveguide of Figure 17 as a function of distance therealong;

[0027] Figure 19 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including a symmetric wedge-like segment positioned within the first section and the first section is partially truncated;

[0028] Figure 20 is a graphical representation of the normalized power coupled into the waveguide of Figure 19 as a function of distance therealong;

[0029] Figure 21 shows an arrangement of a waveguide receptive of N-mode radiation along an axis from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including a symmetric wedge-like segment positioned within the first section, the first section is partially truncated and the second section is offset from the axis;

[0030] Figure 22 is a graphical representation of the normalized power coupled into the waveguide of Figure 21 as a function of distance therealong;

[0031] Figure 23 shows an arrangement of a waveguide receptive of N-mode radiation along an axis from a radiation source wherein the waveguide includes a first section

and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including a symmetric wedge-like segment positioned within the first section, the first section is partially truncated and the second section is offset from the axis;

[0032] Figure 24 is a graphical representation of the normalized power coupled into the waveguide of Figure 23 as a function of distance therealong;

[0033] Figure 25 shows an arrangement of a waveguide receptive of N-mode radiation along an axis from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including a symmetric wedge-like segment positioned within the first section, the first section is partially truncated and the second section is offset from the axis;

[0034] Figure 26 is a graphical representation of the normalized power coupled into the waveguide of Figure 25 as a function of distance therealong;

[0035] Figure 27 is a graphical representation of the power coupled into the waveguide of Figure 17 as a function of distance therealong;

[0036] Figure 28 shows an arrangement of a waveguide receptive of N-mode radiation from a radiation source wherein the waveguide includes a first section and a second section having a refractive index different than that of the first section and wherein the second section includes a segment thereof including an asymmetric wedge-like segmen positioned within the first section and the first section is partially truncated;

[0037] Figure 29 is a graphical representation of the normalized power coupled into the waveguide of Figure 28 as a function of distance therealong;

[0038] Figure 30 shows an arrangement of a waveguide receptive of N-mode radiation along an axis from a radiation source wherein the waveguide includes a first section, a second section and a tapered section and wherein the second section has a refractive index different than that of the first section and the tapered section encompasses a segment of the second section;

[0039] Figure 31 is a graphical representation of the normalized power coupled into the

waveguide of Figure 30 as a function of distance therealong;

[0040] Figure 32 is a three dimensional view of a waveguide device for coupling optical radiation between optical elements;

[0041] Figure 33 is a first configuration of the symmetric wedge-like segment of the second section of the waveguide of Figure 17;

[0042] Figure 34 is a second configuration of the asymmetric wedge-like segment of the second section of the waveguide of Figure 14;

[0043] Figure 35 is a third configuration of the asymmetric wedge-like segment of the second section of the waveguide Figure 14;

[0044] Figure 36 shows an optical beam redirection device as a diffraction grating; and

[0045] Figure 37 shows an optical beam redirection device as a concave surface.

Detailed Description

[0046] Referring to Figure 1, a first embodiment of an optical coupling system 200 for coupling optical energy between optical devices is shown. The optical coupling system 200 comprises an optical beam redirection device 206 such as a prism (acting as a mirror by total internal reflection) or a lens. The surface of the optical beam redirection device 206 may be planar or non-planar. If, for example, the surface is concaved (Fig. 37), more light may be collected from the VCSEL and coupled into other optical components. The surface of the optical beam redirection device 206 may also be patterned or ruled like an optical diffraction grating (Fig. 36) for optical filtering or wavelength selection. All of these designs can be incorporated into the mirrored surface 206 depending upon the application, the required performance or other needs.

[0047]

The optical beam redirection device 206 is receptive of multi-mode radiation 202 (e.g., N-mode radiation where N is an integer) at a distance of "s" from a radiation source 230 such as a vertical cavity surface emitting laser (VCSEL), an edge emitting laser or a multimode optical fiber. The laser output 202 diverges over an approximately symmetric solid angle, χ , of about 15 degrees. The optical beam

redirection device 206 is placed at the distance "s" so as to capture all or substantially all of the radiation 202 emitted by the laser 230. A waveguide 214 is receptive of the N-mode radiation 204 from the optical beam redirection device 206. The waveguide 214 comprises a first section 208 having a thickness of "h", which is receptive of the N-mode radiation 204 from the optical beam redirection device 206. A second section 210 of the waveguide 214 has a thickness of "t" wherein "t" is less than "h". The dimension "h" is approximately 10-100 micrometers (um) and "t" is approximately 2-10 um. A tapered section 212 has a first aperture 226 with a thickness of h joined with the first waveguide section 208 and a second aperture 228 with a thickness of t joined with the second waveguide section 210, thus coupling the N-mode radiation 204 from the first waveguide section 208 to the second waveguide section 210. As best understood from Figure 1, the N-mode radiation 202 may be directed directly into the first section of the waveguide 208. Also in Figure 1, the refractive indices of the first and second waveguide sections 208, 210 and the tapered section 212 are all equal. As seen in Figure 35, the tapered section 212 has a length, "l", of approximately 100-1000 um and also subtends a first angle, α , of about 5 degrees and a second angle, β , perpendicular to the first angle, α , of about 5 degrees measured at or near the second waveguide section 210.

[0048] Typical material compositions of the optical beam redirection device 206, the first waveguide section 208, the second waveguide section 210 and the tapered section 212 are that of special or regular glasses, semiconductors, polymers, optical sol gels, or opto-electrical crystals, etc. The waveguide and tapered structures can be fabricated by using reactive-ion etching (RIE), laser ablation, mechanical sawing, molding, stamping, gray-scale mask lithography and so on.

[0049] In a second embodiment of the invention, as seen in Figure 2, the waveguide 214, which has a refractive index of n_w , may be encased within a cladding 216 having a refractive index of n_c , wherein n_c is less than n_w . Figure 3 depicts a graphical representation at 302 of the normalized power coupled into the second waveguide section 210 of Figure 2 as a function of distance along the tapered section 212 and the second waveguide section 210. The maximum normalized power coupled into the second waveguide section 210 of Figure 2 is about 0.8 normalized units.

[0050] In a third embodiment, as seen in Figures 4 and 5, the first waveguide section 208 and the tapered section 212 are defined by the refractive index, n_w, and the second waveguide section 210 is defined by the refractive index, n_c, wherein n_c is less than n_w. In Figure 5, the second waveguide section 210 includes an additional, elongated top-layer taper 218 which possess the same refractive index as the second waveguide section 210 and extends from the upper surface of the second waveguide section 210 to a point along the tapered section 212, thus providing improved coupling of power between the first waveguide section 208 and the second waveguide section 210. Figure 7 depicts a graphical representation at 306 of the normalized power coupled into the second waveguide section 210 of Figure 5 as a function of distance along the tapered section 212 and the second waveguide section 210.

[0051] In a fourth embodiment, as seen in Figures 8, 9 and 10 and Figures 33, 34 and the second waveguide section 210 includes a segment thereof 220 positioned within the tapered section 212 or within both the tapered section 212 and the first waveguide section 208. In particular, as seen in Figure 8, the aforesaid segment 220 comprises a rectangular shaped segment extending a length, "w", into the tapered section 212 and the first waveguide section 212. Figure 6 depicts a graphical representation at 304 of the normalized power coupled into the second waveguide section 210 of Figure 8 as a function of distance along the tapered section 212 and the second waveguide section 210. In Figure 9, the aforesaid segment 220 comprises a wedge 222 having a generally triangular cross section including a base with a thickness of t joined with the second waveguide section 210. The triangular cross section in Figure 9 also includes an angled apex 5-10 degrees in opposition to the base subtending an angle, γ, of approximately 5-10 degrees. The triangular cross section in Figure 9 is generally a right triangle positioned so that the hypotenuse thereof is first receptive of the N-mode radiation 204 from the tapered section 212, thus coupling the N-mode radiation from the first waveguide section 208 to the second waveguide section 210. In Figure 10, the triangular cross section 220 is inclined with respect to the second waveguide section 210 at angle, θ, of between approximately 5-10 degrees. As best understood from Figures 8, 9 and 10, the first waveguide section 208 acts as a waveguide (e.g.; as a core material), while the cladding thereto is a substrate below and air above.

[0052] In a fifth embodiment, as seen in Figure 11, the second waveguide section 210 encases or envelopes the optical beam redirection device 206, the first waveguide section 208 and the first tapered section 212 of Figure 8.

[0053] Referring to Figures 12, 13 and 14, and Figures 33, 34 and 35, a sixth embodiment of the optical coupling system 200 is shown. In Figures 12, 13 and 14, the cladding 216, having a thickness of c and a refractive index of n_w, is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along an axis 224. The second waveguide section 210, which is symmetric with respect to the axis 224, has a thickness of "t" (less than "c"), a refractive index of n_c (greater than n_w) and a segment thereof 220 positioned within the cladding 216 over a length of b. In Figure 12, the segment of the second waveguide 220 positioned within the cladding 216 is terminated with a square or rectangular end. In Figures 13 and 14, the segment of the second waveguide 220 positioned within the cladding 216 includes a wedge 222. The wedge 222 has a generally triangular cross section including a base with a thickness "t" joined with the second waveguide section 210 and an angled apex opposed to the base. The wedge 222 is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along the axis 224 for coupling the N-mode radiation 204 from the optical beam redirection device 206 to the second waveguide section 210. In Figure 13, the triangular cross section 220 is inclined with respect to the second waveguide section 210 at angle, θ , of between approximately 5-10 degrees. The triangular cross section in Figure 14 is generally a right triangle positioned so that the hypotenuse thereof is first receptive of the N-mode radiation 204 from the tapered section 212, thus coupling the N-mode radiation from the first waveguide section 208 to the second waveguide section 210. As best understood from Figures 12, 13 and 14, in contrast to Figures 8, 9 and 10, the first waveguide section 208 acts as a cladding to the second waveguide section 210. The use of the first waveguide section 208, either as a core or a cladding, depends on how it is applied within the whole structure.

[0054] Referring to Figures 15, 17 and 19, a seventh embodiment is shown. In a fashion similar to that shown in Figure 12, in Figures 15, 17 and 19, the cladding 216, having a thickness of c and a refractive index of n_w, is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along an axis 224. The second

[redacted]

waveguide section 210, which is symmetric with respect to the axis 224, has a thickness of "t" (less than "c"), a refractive index of n_c (greater than n_w) and a segment thereof 220 positioned within the cladding 216 over a length of "b". In Figure 15, the segment of the second waveguide 220 positioned within the cladding 216 is terminated with a square or rectangular end. Figure 16 depicts a graphical representation at 308 of the normalized power coupled into the second waveguide section 210 of Figure 15 as a function of distance along the cladding 216 and the second waveguide section 210.

[0055] [0055] Also in a fashion similar to Figures 13 and 14, in Figures 17 and 19, the segment of the second waveguide 220 positioned within the cladding 216 includes a wedge 222. The wedge 222 has a generally triangular cross section including a base with a thickness "t" joined with the second waveguide section 210 and an angled apex opposed to the base. The wedge 222 is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along the axis 224 for coupling the N-mode radiation 204 from the optical beam redirection device 206 to the second waveguide section 210. Figure 18 depicts a graphical representation at 310 of the normalized power coupled into the second waveguide section 210 of Figure 17 as a function of distance along the cladding 216 and the second waveguide section 210. Figure 20 depicts a graphical representation at 312 of the normalized power coupled into the second waveguide section 210 of Figure 19 as a function of distance along the cladding 216 and the second waveguide section 210.

[0056] However, it is seen in Figures 15, 17 and 19, that the cladding 216 is truncated over a segment thereof having a length "d" wherein the second waveguide section 210 is not enveloped by the cladding 216 over that segment.

[0057]

Also as best understood from Figures 15, 17 and 19, in contrast to Figures 8, 9 and 10, the first waveguide section 208 acts as a cladding to the second waveguide section 210. The use of the first waveguide section 208, either as a core or a cladding, depends on how it is applied within the whole structure. Still further, as can be seen in Figures 18 and 20, the addition of the wedge 222 in Figures 17 and 19 respectively, provides a noticeable improvement in the coupling of energy from the cladding 216 into the second waveguide section 210 (about 0.9 normalized units for the

arrangement in Figure 17 and about 0.8 normalized units for the arrangement in Figure 19), as compared to that seen in Figure 16 for a second waveguide section 210 with a wedge 222 (about 0.35 normalized units). However, in comparing the coupling in Figures 20 and 22, it is seen that the thickness of the second waveguide section 210 has less of an impact on coupling than the addition of the wedge 222.

[0058] Referring to Figures 21, 23 and 25, a seventh embodiment is shown. In a fashion similar to that shown in Figure 12, in Figures 21, 23 and 25, the cladding 216, having a thickness of "c" and a refractive index of n_w, is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along an axis 224. The second waveguide section 210, which is symmetric with respect to the axis 224, has a thickness of t (less than "c"), a refractive index of n_c (greater than n_w) and a segment thereof 220 positioned within the cladding 216 over a length of "b". In Figure 21, the segment of the second waveguide 220 positioned within the cladding 216 is terminated with a square or rectangular end. Figure 22 depicts a graphical representation at 314 of the normalized power coupled into the second waveguide section 210 of Figure 21 as a function of distance along the cladding 216 and the second waveguide section 210.

[0059] Also in a fashion similar to Figures 13 and 14, in Figures 23 and 25, the segment of the second waveguide 220 positioned within the cladding 216 includes a wedge 222. The wedge 222 has a generally triangular cross section including a base with a thickness "t" joined with the second waveguide section 210 and an angled apex opposed to the base. The wedge 222 is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along the axis 224 for coupling the N-mode radiation 204 from the optical beam redirection device 206 to the second waveguide section 210. Figure 24 depicts a graphical representation at 316 of the normalized power coupled into the second waveguide section 210 of Figure 23 as a function of distance along the cladding 216 and the second waveguide section 210. Figure 26 depicts a graphical representation at 318 of the normalized power coupled into the second waveguide section 210 of Figure 25 as a function of distance along the cladding 216 and the second waveguide section 210.

[0060]

Again, it is seen in Figures 21, 23 and 25, that the cladding 216 is truncated over

a segment thereof having a length "d" wherein the second waveguide section 210 is not enveloped by the cladding 216 over that segment. However, it is also seen in Figures 21, 23 and 25 that the second waveguide section 210 is offset from the axis 224 by a distance "r.

[0061] As seen in Figures 22 and 23, the amount of energy coupled from the cladding 216 into the second waveguide section 210, for the same offset "r" in the arrangements of Figures 21 and 23 respectively, is approximately the same (about 0.6 normalized units) despite a thinner second waveguide section 210 in Figure 23. Thus, the thickness of the second waveguide section 210 does not dictate the coupling efficiency. However, as seen in Figure 25, for too large of an offset "ro", the coupling efficiency is dramatically reduced (to about 0.05 normalized units).

[0062] [0062] As shown in Figures 22, 24 and 26, a smaller offset "r" yields a better coupling. However, a certain amount of offset "r" may occur due to fabrication processing, etc. Therefore, innovative solutions are disclosed in Figure 10 (using a special taper design for "drawing" the energy into a preferred waveguide layer) and in Figure 33 (using a tapered cladding to "squeeze" the energy into a preferred waveguide layer).

[0063] As best understood from Figures 21, 23 and 25, in contrast to Figures 8, 9 and 10, the first waveguide section 208 acts as a cladding to the second waveguide section 210. The use of the first waveguide section 208, either as a core or a cladding, depends on how it is applied within the whole structure.

[0064] In the arrangement of Figure 17 a symmetric wedge 222 is shown, and in Figure 28 an asymmetric wedge 222 is shown. The difference in the coupling efficiency between the arrangements of Figures 17 and 28 is seen in comparing Figures 27 and 29 respectively. In Figure 27 it is seen that the symmetric wedge 222, has a higher coupling efficiency (about 0.9 normalized units) than that of Figure 29 (about 0.8 normalized units).

[0065]

In the arrangement of Figure 25, a symmetric wedge 222 and the second waveguide section 210 are off set by a distance "r" from the axis 224. As seen in Figure 26 this arrangement yields a relatively poor coupling efficiency 318 of about

0.05 normalized units. Referring to Figure 30 an eighth embodiment is shown. In Figure 30, the cladding 216, again having a thickness of "c" and a refractive index of n_w, is receptive of the N-mode radiation 204 from the optical beam redirection device 206 along an axis 224. The tapered section 212 has a first aperture 226 with a thickness of h joined with the cladding 216 and a second aperture 228 opposed to and smaller than the first aperture 226. Again, as seen in Figure 32, the tapered section 212 in Figure 30 has a length, "l", of approximately 100-1000 um and also subtends a first angle, α , of about 5-10 degrees and a second angle, β , perpendicular to the first angle, α , of about 5-50 degrees. The tapered section 212 is receptive of the N-mode radiation at the first aperture 226 from the cladding 216. In Figure 30, the second waveguide section 210 is offset from the axis 224 by a distance "r" and includes a segment 220 thereof positioned and encased within the tapered section 212. The segment 220 of the second waveguide section 210 positioned within the tapered section 212 includes a wedge 222. The wedge 222 has a generally triangular cross section including a base with a thickness "t" joined with the second waveguide section 210 and an angled apex opposed to the base. The wedge 222 is receptive of the N-mode radiation 204 from the tapered section 212. Figure 31 depicts a graphical representation at 326 of the normalized power coupled into the second waveguide section 210 of Figure 30 as a function of distance along the tapered section 212 and the second waveguide section 210. As can be seen in Figure 31, the coupling efficiency for the arrangement shown in Figure 30 is an improvement over that shown in Figure 26 relating to the arrangement of Figure 25.

[0066] Figures 33, 34 and 35 show various configurations of the wedge-like segment of the second section of the waveguide. In general, the taper and wedge are "gentle" or "slow." That is, the angles, a and b, of these tapers or wedges are small. Therefore, " h" and "q" are much larger than the waveguide thickness "t" and width "w". Thus, the angles a and b in Figure 32 will be then determined accordingly. The length of the wedge-like segment 222 is "k" and the angles θ and γ of Figures 33, 34 and 35 are also relatively small. Thus, the wedge-like segment 222 is accordingly elongated in nature. As best understood the tapered section 212 and wedge-like segments 222 are all of an elongated nature wherein the angles a, b, θ and γ are relatively small or acute.

[0067] Any references to first, second, etc., or front or back, right or left, top or bottom, upper or lower, horizontal or vertical, or any other phrase indicating the relative position of one quantity or variable with respect to another are, unless noted otherwise, intended for the convenience of description of the invention, and do not limit the present invention or its components to any one positional or spatial orientation. All dimensions of the components in the attached Figures can vary with a potential design and the intended use of an embodiment without departing from the scope of the invention.

[0068] While the invention has been described with reference to several embodiments thereof, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.